APPENDIX A

SEISMIC-FORCE-RESISTING ELEMENTS IN BUILDINGS

This handbook discusses techniques for rehabilitating the seismic resistance of the following 15 common building types:

1. Wood Light Frame
2. Wood, Commercial and Industrial
3. Steel Moment Frame
4. Steel Braced Frame
5. Steel Light Frame
6. Steel Frame with Concrete Shear Walls
7. Steel with Infill Masonry Shear Walls
8. Concrete Moment Frame
9. Concrete Shear Walls
10. Concrete Frame with Infill Walls
11. Precast/Tilt-Up Concrete Walls with Lightweight Flexible Diaphragm
12. Precast Concrete Frames with Concrete Shear Walls
13. Reinforced Masonry Bearing Walls with Wood/Metal Deck Diaphragms
14. Reinforced Masonry Bearing Walls with Precast Concrete Diaphragms
15. Unreinforced Masonry Bearing Wall Buildings

The lateral-force-resisting elements of buildings can be categorized into the following subsystems: vertical elements resisting lateral forces, diaphragms, foundations, and the connections between the subsystems. The 15 common building types considered in this report can be composed of various subsystem types. The construction of each subsystem can vary. For example, diaphragms can be constructed of timber, steel or concrete. The technique to rehabilitate a deficient subsystem and hence a deficient building depends upon the type of construction of that subsystem. The following tables present common construction of the lateral-force-resisting subsystems for the 15 common building types. These tables are provided to aid the reader in determining the types of subsystems likely to be present in a building of a given type. With an understanding of the subsystem construction and the subsystem deficiencies, the techniques presented in Chapter 3 can be investigated to determine effective ways to rehabilitate the seismic resistance of a given existing building.

TABLE A1
STRUCTURAL ELEMENTS OF COMMON BUILDING TYPE 1--WOOD, LIGHT FRAME

Floor or Roof Diaphragm	Vertical-Resisting Elements	Foundations	Connections
Timber framing with plywood, straight-laid, or diagonal sheathing.	Wood stud walls with let-in or cut-in timber bracing or plywood, straight-laid, or diagonal sheathing.	Spread footings, piles, or drilled piers.	Diagonal wire or strut bracing of ceilings from floor or roof diaphragms. Bracing or lateral support of walls and partitions from ceilings or diaphragms. Nailing and blocking for direct shear transfer from horizontal diaphragms to shear walls or vertical bracing. Drag struts to collect shear from horizontal diaphragms for transfer to shear walls or vertical bracing. Bolting of shear walls and vertical bracing to concrete slabs or foundation walls. Tension ties or hold-downs for shear walls and vertical bracing. Nailing or bolting of vertical bracing.

TABLE A2
STRUCTURAL ELEMENTS OF COMMON BUILDING TYPE 2--WOOD, COMMERCIAL AND INDUSTRIAL

Floor or Roof Diaphragm	Vertical-Resisting Elements	Foundations	Connections
Timber framing with plywood, straight-laid, or diagonal sheathing. (Floor or roof decking may be 2-inch material).	Wood stud walls with let-in or cut-in timber bracing or plywood, straight-laid, or diagonal sheathing. Knee bracing or diagonal bracing of timber columns.	Spread footings, piles, or drilled piers.	Diagonal wire or strut bracing of ceilings from floor or roof diaphragms. Bracing or lateral support of walls and partitions from ceilings or diaphragms. Nailing and blocking for direct shear transfer from horizontal diaphragms to shear walls or vertical bracing. Drag struts to collect shear from horizontal diaphragms for transfer to shear walls or vertical bracing. Bolting of shear walls and vertical bracing to concrete slabs or foundation walls. Tension ties or hold-downs for shear walls and vertical bracing. Nailing or bolting of vertical bracing.

TABLE A3

STRUCTURAL ELEMENTS OF COMMON BUILDING TYPE 3--STEEL MOMENT FRAME

Floor or Roof Diaphragm	Vertical-Resisting Elements	Foundations	Connections
Timber framing with plywood, straight-laid, or diagonal sheathing. Reinforced concrete slab supported on structural steel floor framing members. Steel decking with or without concrete fill.	Moment resisting structural steel frames.	Spread footings, piles, or drilled piers.	Diagonal wire or strut bracing of ceilings from floor or roof diaphragms. Bracing or lateral support of walls and partitions from ceilings or diaphragms. Nailing and blocking for direct shear transfer from horizontal diaphragms to shear walls or vertical bracing. Drag struts to collect shear from horizontal diaphragms for transfer to shear walls or vertical bracing. Shear studs or other connections of concrete diaphragm to steel chord members. Welding, shear studs, or other connections of steel deck diaphragms to structural steel framing. Splice detail of steel chord members. Beam/column connections. Beam/column panel joint details. Column splice details. Column base details.

TABLE A4
STRUCTURAL ELEMENTS OF COMMON BUILDING TYPE 4--STEEL BRACED FRAME

Floor or Roof Diaphragm	Vertical-Resisting Elements	Foundations	Connections
Timber framing with plywood, straight-laid, or diagonal sheathing. Reinforced concrete slab supported on structural steel floor framing members. Steel decking with or without concrete fill.	Concentric steel bracing in diagonal, X, K, or chevron configuration. May also have moment resisting structural steel frames.	Spread footings, piles, or drilled piers.	Diagonal wire or strut bracing of ceilings from floor or roof diaphragms. Bracing or lateral support of walls and partitions from ceilings or diaphragms. Nailing and blocking for direct shear transfer from horizontal diaphragms to shear walls or vertical bracing. Drag struts to collect shear from horizontal diaphragms for transfer to shear walls or vertical bracing. Shear studs or other connections of concrete diaphragm to steel chord members. Welding, shear studs, or other connections of steel deck diaphragms to structural steel framing. Splice detail of steel chord members. Beam/column connections. Beam/column panel joint details. Column splice details. Column base details. Bolted or welded bracing connections.

TABLE A5
STRUCTURAL ELEMENTS OF COMMON BUILDING TYPE 5--STEEL, LIGHT FRAME

Floor or Roof Diaphragm	Vertical-Resisting Elements	Foundations	Connections
Timber framing with plywood, straight-laid, or diagonal sheathing. Reinforced concrete slab supported on structural steel floor framing members. Steel decking with or without concrete fill.	Moment resisting structural steel frames. Concentric light steel bracing in diagonal or X configuration.	Spread footings, piles, or drilled piers.	Diagonal wire or strut bracing of ceilings from floor or roof diaphragms. Bracing or lateral support of walls and partitions from ceilings or diaphragms. Nailing and blocking for direct shear transfer from horizontal diaphragms to shear walls or vertical bracing. Drag struts to collect shear from horizontal diaphragms for transfer to shear walls or vertical bracing. Shear studs or other connections of concrete diaphragm to steel chord members. Welding, shear studs, or other connections of steel deck diaphragms to structural steel framing. Splice detail of steel chord members. Beam/column connections. Beam/column panel joint details. Column splice details. Column base details. Bolted or welded bracing connections.

TABLE A6
STRUCTURAL ELEMENTS OF COMMON BUILDING TYPE 6--STEEL FRAME WITH CONCRETE SHEAR WALLS

Floor or Roof Diaphragm	Vertical-Resisting Elements	Foundations	Connections
Reinforced concrete slab supported on structural steel floor framing members. Steel decking with or without concrete fill.	Nonmoment-resisting steel frames. Reinforced concrete shear walls. May also have moment resisting structural steel frames.	Spread footings, piles, or drilled piers.	Diagonal wire or strut bracing of ceilings from floor or roof diaphragms. Bracing or lateral support of walls and partitions from ceilings or diaphragms. Shear studs or other connections of concrete diaphragm to steel chord members. Welding, shear studs, or other connections of steel deck diaphragms to structural steel framing. Splice detail of steel chord members. Beam/column connections. Beam/column panel joint details. Column splice details. Column base details. Connection of concrete shear walls to floor or roof diaphragms. Development of boundary members for concrete shear walls.

TABLE A7
STRUCTURAL ELEMENTS OF COMMON BUILDING TYPE 7--STEEL WITH INFILL MASONRY SHEAR WALLS

Floor or Roof Diaphragm	Vertical-Resisting Elements	Foundations	Connections
Timber framing with plywood, straight-laid, or diagonal sheathing. Reinforced concrete slab supported on structural steel floor framing members. Steel decking with or without concrete fill.	Nonmoment-resisting steel frames. Unreinforced masonry walls. May also have moment resisting structural steel frames.	Spread footings, piles, or drilled piers.	Diagonal wire or strut bracing of ceilings from floor or roof diaphragms. Bracing or lateral support of walls and partitions from ceilings or diaphragms. Nailing and blocking for direct shear transfer from horizontal diaphragms to shear walls or vertical bracing. Drag struts to collect shear from horizontal diaphragms for transfer to shear walls or vertical bracing. Shear studs or other connections of concrete diaphragm to steel chord members. Welding, shear studs, or other connections of steel deck diaphragms to structural steel framing. Splice detail of steel chord members. Beam/column connections. Beam/column panel joint details. Column splice details. Column base details. Connection of masonry walls to steel framing.

TABLE A8

STRUCTURAL ELEMENTS OF COMMON BUILDING TYPE 8--CONCRETE MOMENT FRAME

Floor or Roof Diaphragm	Vertical-Resisting Elements	Foundations	Connections
Reinforced concrete slab monolithic with reinforced concrete beams and girders.	Reinforced concrete frames.	Spread footings, piles, or drilled piers.	Diagonal wire or strut bracing of ceilings from floor or roof diaphragms. Bracing or lateral support of walls and partitions from ceilings or diaphragms. Beam/column panel joint details. Column shear reinforcement and confinement.

TABLE A9
STRUCTURAL ELEMENTS OF COMMON BUILDING TYPE 9--CONCRETE SHEAR WALLS

Floor or Roof Diaphragm	Vertical-Resisting Elements	Foundations	Connections
Reinforced concrete slab monolithic with reinforced concrete beams and girders.	Reinforced concrete shear walls.	Spread footings, piles, or drilled piers.	Diagonal wire or strut bracing of ceilings from floor or roof diaphragms. Bracing or lateral support of walls and partitions from ceilings or diaphragms. Connection of concrete shear walls to floor or roof diaphragms. Development of boundary members for concrete shear walls. Concrete diaphragm chord details.

TABLE A10
STRUCTURAL ELEMENTS OF COMMON BUILDING TYPE 10--CONCRETE FRAME WITH INFILL WALLS

Floor or Roof Diaphragm	Vertical-Resisting Elements	Foundations	Connections
Timber framing with plywood, straight-laid, or diagonal sheathing. Reinforced concrete slab monolithic with reinforced concrete beams and girders.	Reinforced concrete frames. Unreinforced masonry walls.	Spread footings, piles, or drilled piers.	Diagonal wire or strut bracing of ceilings from floor or roof diaphragms. Bracing or lateral support of walls and partitions from ceilings or diaphragms. Connection of timber floor or roof diaphragms to concrete frames. Connection of concrete floor or roof diaphragms to concrete frames. Connection of masonry walls to concrete frames. Beam/column joint details. Column shear reinforcement and confinement.

TABLE A11
STRUCTURAL ELEMENTS OF COMMON BUILDING TYPE 11--PRECAST/TILT-UP CONCRETE WALLS WITH LIGHTWEIGHT FLEXIBLE DIAPHRAGM

Floor or Roof Diaphragm	Vertical-Resisting Elements	Foundations	Connections
Timber framing with plywood, straight-laid, or diagonal sheathing. Reinforced concrete slab monolithic with reinforced concrete beams and girders. Steel decking with or without concrete fill.	Precast concrete walls.	Spread footings, piles, or drilled piers.	Diagonal wire or strut bracing of ceilings from floor or roof diaphragms. Bracing or lateral support of walls and partitions from ceilings or diaphragms. Welding, shear studs, or other connections of steel deck diaphragms to structural steel framing. Connection of timber floor or roof diaphragms and precast walls. Connection of concrete floor or roof diaphragms to precast walls. Connection of steel deck floor or roof diaphragms to precast walls. Vertical precast panel connections. Tension ties or hold-down connections for precast panels. Diaphragm chord details for timber, steel decking, and concrete diaphragm. Base detail for precast panels.

TABLE A12
STRUCTURAL ELEMENTS OF COMMON BUILDING TYPE 12--PRECAST CONCRETE FRAMES WITH CONCRETE SHEAR WALLS

Floor or Roof Diaphragm	Vertical-Resisting Elements	Foundations	Connections
Reinforced concrete slab monolithic with reinforced concrete beams and girders.	Precast concrete frames. Reinforced concrete shear walls.	Spread footings, piles, or drilled piers.	Diagonal wire or strut bracing of ceilings from floor or roof diaphragms. Bracing or lateral support of walls and partitions from ceilings or diaphragms. Connection of concrete floor or roof diaphragms to precast frames or shear walls. Development of boundary members for concrete shear walls. Beam/column joint details. Column shear reinforcement and confinement. Concrete frame splice details.

TABLE A13
STRUCTURAL ELEMENTS OF COMMON BUILDING TYPE 13--REINFORCED MASONRY WALLS WITH WOOD/METAL DECK

Floor or Roof Diaphragm	Vertical-Resisting Elements	Foundations	Connections
Timber framing with plywood, straight-laid, or diagonal sheathing. Steel decking with or without concrete fill.	Unreinforced masonry bearing walls.	Spread footings, piles, or drilled piers.	Diagonal wire or strut bracing of ceilings from floor or roof diaphragms. Bracing or lateral support of walls and partitions from ceilings or diaphragms. Welding, shear studs, or other connections of steel deck diaphragms to structural steel framing. Connection of timber or steel decking floor or roof diaphragms to masonry walls. Tension ties or hold-downs for masonry walls.

TABLE A14
STRUCTURAL ELEMENTS OF COMMON BUILDING TYPE 14--REINFORCED MASONRY WALLS WITH PRECAST CONCRETE DECK

Floor or Roof Diaphragm	Vertical-Resisting Elements	Foundations	Connections
Precast concrete units (planks, cored slabs, tees, etc.)	Reinforced masonry walls.	Spread footings, piles, or drilled piers.	Diagonal wire or strut bracing of ceilings from floor or roof diaphragms. Bracing or lateral support of walls and partitions from ceilings or diaphragms. Connection of precast floor or roof units to shear walls. Connections between adjacent precast floor or roof units. Tension ties or hold-downs for masonry walls.

TABLE A15
STRUCTURAL ELEMENTS OF COMMON BUILDING TYPE 15--UNREINFORCED MASONRY BEARING WALLS

Floor or Roof Diaphragm	Vertical-Resisting Elements	Foundations	Connections
Timber framing with plywood, straight-laid, or diagonal sheathing. Reinforced concrete slab supported on structural steel floor framing members. Reinforced concrete slab monolithic with reinforced concrete beams and girders.	Unreinforced masonry walls.	Spread footings, piles, or drilled piers.	Diagonal wire or strut bracing of ceilings from floor or roof diaphragms. Bracing or lateral support of walls and partitions from ceilings or diaphragms. Connection of timber or concrete floor or roof diaphragms to masonry walls. Development of diaphragm chords in timber or concrete floor or roof diaphragms. Tension ties or hold-downs for masonry walls.

APPENDIX B

SUMMARY OF STRENGTHENING TECHNIQUES

The deficiencies and alternative strengthening techniques discussed in Chapter 3 are summarized here as follows:

Table B1	Moment Resisting Systems Steel Moment Frames Concrete Moment Frames Moment Frames with Infill Walls Precast Concrete Moment Frames
Table B2	Shear Walls Reinforced Concrete or Reinforced Masonry Precast Concrete Unreinforced Masonry Shear Walls in Wood Frame Buildings
Table B3	Braced Frames
Table B4	Diaphragms
Table B5	Foundations
Table B6	Diaphragm to Vertical Element Connections
Table B7	Vertical Element to Foundation Connections

TABLE B1
MOMENT RESISTING SYSTEMS

STEEL MOMENT FRAMES	
Deficiency	**Strengthening Techniques**
Inadequate moment/shear capacity of beams, columns, or their connections	1. Increasing the moment capacity of the members and connections by adding cover plates or other steel sections to the flanges Or by boxing members. 2. Increasing the moment and shear capacity of the members and connections by providing steel gusset plates or knee braces. 3. Reducing the stresses in the existing frames by providing supplemental vertical-resisting elements (i.e., additional moment frames, braces, or shear walls) as discussed in Sec. 3.4. 4. Providing lateral bracing of unsupported flanges to increase capacity limited by tendency for lateral/torsional buckling. 5. Encasing the columns in concrete.
Inadequate beam/column panel zone capacity	1. Providing welded continuity plates between the column flanges. 2. Providing stiffener plates welded to the column flanges and web. 3. Providing web doubler plates at the column web. 4. Reducing the stresses in the panel zone by providing supplemental vertical-resisting elements (i.e., additional moment frames, braces, or shear walls) as discussed in Sec. 3.4.
Excessive drift	1. Increasing the capacity and, hence, the stiffness of the existing moment frame by cover plates or boxing. 2. Increasing the stiffness of the beams and columns at their connections by providing steel gusset plates to form haunches. 3. Reducing the drift by providing supplemental vertical-resisting elements (i.e., additional moment frames, braces, or shear walls) as discussed in Sec. 3.4. 4. Increasing the stiffness by encasing columns in reinforced concrete. 5. Reducing the drift by adding supplemental damping as discussed in Sec. 4.
CONCRETE MOMENT FRAMES	
Inadequate ductile bending or shear capacity in the beams or columns and lack of confinement, frequently in the joints	1. Increasing the ductility and capacity by jacketing the beam and column joints or increasing the beam or column capacities. 2. Reducing the seismic stresses in the existing frames by providing supplemental vertical-resisting elements (i.e., additional moment frames, braces, or shear walls) as discussed in Sec. 3.4. 3. Changing the system to a shear wall system by infilling the reinforced concrete frames with reinforced concrete.

TABLE B1--continued

MOMENT FRAMES WITH INFILL WALLS	
Crushing of the infill at the upper and lower corners due to the diagonal compression strut type action of the infill wall	1. Eliminating the hazardous effects of the infill by providing a gap between the infill and the frame and providing out-of-plane support. 2. Treating the infill frame as a shear wall and correcting the deficiencies as described in Sec. 3.2.
Shear failure of the beam/column connection in the steel frames or direct shear transfer failure of the beam or column in concrete frames	
Tensile failure of the columns or their connections due to the uplift forces resulting from the braced frame action induced by the infill	
Splitting of the infill due to the orthogonal tensile stresses developed in the diagonal compressive strut	
Loss of infill by out-of-plane forces due to loss of anchorage or excessive slenderness of the infill wall	
PRECAST CONCRETE MOMENT FRAMES	
Inadequate capacity and/or ductility of the joints between the precast units	1. Removing existing concrete in the precast elements to expose the existing reinforcing steel, providing additional reinforcing steel welded to the existing steel (or drilled and grouted), and replacing the removed concrete with cast-in-place concrete. 2. Reducing the forces on the connections by providing supplemental vertical-resisting elements (i.e., additional moment frames, braces, or shear walls) as discussed in Sec. 3.4.

TABLE B2
SHEAR WALLS

REINFORCED CONCRETE OR REINFORCED MASONRY SHEAR WALLS	
Deficiency	**Strengthening Techniques**
Inadequate shear capacity	1. Increasing the effectiveness of the existing walls by filling in door or window openings with reinforced concrete or masonry. 2. Providing additional thickness to the existing walls with a poured-in-place or pneumatically applied (i.e., shotcrete) reinforced concrete overlay anchored to the inside or outside face of the existing walls. 3. Reducing the shear or flexural stresses in the existing walls by providing supplemental vertical-resisting elements (i.e., shear walls, braces, or external buttresses) as discussed in Sec. 3.4.
Inadequate flexural capacity	1. Increasing the effectiveness of the existing walls by filling in door or window openings with reinforced concrete or masonry. 2. Providing additional thickness to the existing walls with a poured-in-place or pneumatically applied (i.e., shotcrete) reinforced concrete overlay anchored to the inside or outside face of the existing walls. 3. Reducing the shear or flexural stresses in the existing walls by providing supplemental vertical-resisting elements (i.e., shear walls, braces, or external buttresses) as discussed in Sec. 3.4.
Inadequate shear or flexural capacity in the coupling beams between shear walls or piers	1. Eliminating the coupling beams by filling in openings with reinforced concrete. 2. Removing the existing beams and replacing with new stronger reinforced beams. 3. Adding reinforced concrete to one or both faces of the wall and providing an additional thickness to the existing wall. 4. Reducing the shear or flexural stresses in the connecting beams by providing additional vertical-resisting elements (i.e., shear walls, braces, or external buttresses) as discussed in Sec. 3.4.
PRECAST CONCRETE SHEAR WALLS	
Inadequate shear or flexural capacity in the wall panels	1. Increasing the shear and flexural capacity of walls with significant openings for doors or windows by infilling the existing openings with reinforced concrete. 2. Increasing the shear or flexural capacity by adding reinforced concrete (poured-in-place or shotcrete) at the inside or outside face of the existing walls. 3. Adding interior shear walls to reduce the flexural or shear stress in the existing precast panels.

TABLE B2--continued

PRECAST CONCRETE SHEAR WALLS--continued	
Inadequate interpanel shear or flexural capacity	1. Making each panel act as a cantilever to resist in-plane forces (by adding or strengthening tie-downs, edge reinforcement, footings). 2. Providing a continuous wall by exposing the reinforcing steel in the edges of adjacent units, adding ties, and repairing with concrete.
Inadequate out-of-plane flexural capacity	1. Providing pilasters at and/or between the interpanel joints. 2. Adding horizontal beams between the columns or pilasters at mid-height of the wall.
Inadequate shear or flexural capacity in coupling beams	1. Eliminating the coupling beams by filling in openings with reinforced concrete. 2. Removing the existing beams and replacing with new stronger reinforced beams. 3. Adding reinforced concrete to one or both faces of the wall and providing an additional thickness to the existing wall. 4. Reducing the shear or flexural stresses in the connecting beams by providing additional vertical-resisting elements (i.e., shear walls, braces, or external buttresses) as discussed in Sec. 3.4.2
UNREINFORCED MASONRY SHEAR WALLS	
Inadequate in-plane shear and out-of-plane flexural capacity of the walls	1. Providing additional shear capacity by placing reinforcing steel on the inside or outside face of the wall and applying new reinforced concrete. 2. Providing additional capacity for out-of-plane lateral forces by adding reinforcing steel to the wall utilizing the center coring technique. 3. Providing additional capacity for out-of-plane lateral forces by adding thin surface treatments (e.g., plaster with wire mesh and portland cement mortar) at the inside and outside faces of existing walls. 4. Filling in existing window or door openings with reinforced concrete. 5. Providing additional shear walls at the interior or perimeter of the building or providing external buttresses.
Inadequate shear capacity of the coupling beam	1. Filling in openings with reinforced concrete. 2. Removing existing connecting beams and replacing them with properly designed new reinforced concrete beams. 3. Providing additional shear walls at interior or perimeter of building or external buttresses.

TABLE B2--continued

SHEAR WALLS IN WOOD FRAME BUILDINGS	
Inadequate shear capacity of the wall	1. Increasing the shear capacity by providing additional nailing to the existing finish material. 2. Increasing the shear capacity by adding plywood sheathing to one or both sides of the wall. 3. Reducing the loads on the wall by providing supplemental shear walls to the interior or perimeter of the building.
Inadequate uplift or hold-down capacity of the wall	1. Increasing the tensile capacity of the connections at the edge of the shear walls by providing metal connectors. 2. Reducing the overturning moments by providing supplemental vertical-resisting elements as discussed in Sec. 3.4.

TABLE B3
BRACED FRAMES

STEEL CONCENTRICALLY BRACED FRAMES (including chevron or K-bracing)	
Deficiency	**Strengthening Techniques**
Inadequate lateral force capacity of the bracing system governed by buckling of the compression brace	1. Increasing the capacity of the braces by adding new members thus increasing the area and reducing the radius of gyration of the braces. 2. Increasing the capacity of the member by reducing the unbraced length of the existing member by providing secondary braces. 3. Providing greater capacity by removing and replacing the existing members with new members of greater capacity. 4. Reducing the loads on the braces by providing supplemental vertical-resisting elements (i.e., shear walls, braces, or eccentric bracing) as discussed in Sec. 3.4.
Inadequate capacity of the brace connection	1. Increasing the capacity of the connections by additional bolting or welding. 2. Increasing the capacity of the connections by removing and replacing the connection with members of greater capacity. 3. Reducing the loads on the braces and their connections by providing supplemental vertical-resisting elements (i.e., shear walls, braces, or eccentric bracing) as discussed in Sec. 3.4.
Inadequate axial load capacity in the columns or beams of the bracing system	1. Providing additional axial load capacity by adding cover plates to the member flanges or by boxing the flanges. 2. Providing additional axial load capacity by jacketing the existing members with reinforced concrete. 3. Reducing the loads on the beams and columns by providing supplemental vertical-resisting elements (i.e., shear walls, braces, or eccentric bracing) as discussed in Sec. 3.4.

TABLE B3--continued

ROD OR OTHER TENSION BRACING	
Inadequate tension capacity of the rod, tensile member, or its connection	1. Increasing the capacity by strengthening the existing tension members. 2. Increasing the capacity by removing the existing tension members and replacing with new members of greater capacity. 3. Increasing the capacity by removing the existing tension member and replacing it with diagonal or X-bracing capable of resisting compression as well as tension forces. 4. Reducing the forces on the existing tension members by providing supplemental vertical-resisting elements (i.e., additional tension rods) as discussed in Sec. 3.4.
Inadequate axial capacity of the beams or columns in the bracing system	1. Increasing the axial capacity by adding cover plates to the existing flanges or by boxing the existing flanges. 2. Reducing the forces on the existing columns or beams by providing supplemental vertical-resisting elements (i.e., braced frames or shear walls) as discussed in Sec. 3.4.
ECCENTRIC BRACING	
Nonconformance with current design standards	1. Ensuring that the system is balanced (i.e., there is a link beam at one end of each brace), the brace and the connections are designed to develop shear or flexural yielding in the link, the connection is a full moment connection, where the link beam has an end at a column, and lateral bracing is provided to prevent out-of-plane beam displacements that would compromise the intended action. 2. Providing supplemental vertical-resisting elements such as additional eccentric braced frames.

TABLE B4
DIAPHRAGMS

TIMBER DIAPHRAGMS (straight-laid or diagonal sheathing or plywood)	
Deficiency	**Strengthening Techniques**
Inadequate shear capacity of the diaphragm	1. Increasing the capacity of the existing timber diaphragm by providing additional nails or staples with due regard for wood splitting problems. 2. Increasing the capacity of the existing timber diaphragm by means of a new plywood overlay. 3. Reducing the diaphragm span through the addition of supplemental vertical-resisting elements (i.e., shear wall or braced frames) as discussed in Sec. 3.4.
Inadequate chord capacity of the diaphragm	1. Providing adequate nailed or bolted continuity splices along joists or fascia parallel to the chord. 2. Providing a new continuous steel chord member along the top of the diaphragm. 3. Reducing the stresses on the existing chords by reducing the diaphragms, span through the addition of new shear walls or braced frames as discussed in Sec. 3.4.
Excessive shear stresses at diaphragm openings or at plan irregularities	1. Reducing the local stresses by distributing the forces along the diaphragm by means of drag struts. 2. Increasing the capacity of the diaphragm by overlaying the existing diaphragm with plywood and nailing the plywood through the sheathing at the perimeter of the sheets adjacent to the opening or irregularity. 3. Reducing the diaphragm stresses by reducing the diaphragm spans through the addition of supplemental shear walls or braced frames as discussed in Sec. 3.4.
Inadequate stiffness of the diaphragm resulting in excessive diaphragm deformations	1. Increasing the stiffness of the diaphragm by the addition of a new plywood overlay. 2. Reducing the diaphragm span and hence reducing the displacements by providing new supplemental vertical-resisting elements such as shear walls or braced frames as discussed in Sec. 3.4.
CONCRETE DIAPHRAGMS (monolithic concrete diaphragms--i.e., reinforced concrete or post-tensioned concrete)	
Inadequate in-plane shear capacity of the concrete diaphragm	1. Increasing the shear capacity by overlaying the existing concrete diaphragm with a new reinforced concrete topping slab. 2. Reducing the shear in the existing concrete diaphragm by providing supplemental vertical-resisting elements (i.e., shear walls or braced frames) as discussed in Sec. 3.4.

TABLE B4--continued

Inadequate diaphragm chord capacity	1. Increasing the flexural capacity by removing the edge of the diaphragm slab and casting a new chord member integral with the slab. 2. Adding a new chord member by providing a new reinforced concrete or steel member above or below the slab and connecting the new member to the existing slab with drilled and grouted dowels or bolts as discussed in Sec. 3.5.4.3. 3. Reducing the existing flexural stresses by providing supplemental vertical-resisting elements (i.e., shear walls or braced frames) as discussed in Sec. 3.4.
Excessive shear stresses at the diaphragm openings or plan irregularities	1. Reducing the local stresses by distributing the forces along the diaphragm by means of structural steel or reinforced concrete elements cast beneath the slab and made integral through the use of drilled and grouted dowels. 2. Increasing the capacity of the concrete by providing a new concrete topping slab in the vicinity of the opening and reinforcing with trim bars. 3. Removing the stress concentration by filling in the diaphragm opening with reinforced concrete. 4. Reducing the shear stresses at the location of the openings by adding supplemental vertical-resisting elements (i.e., shear walls or braced frames) as discussed in Sec. 3.4.

TABLE B4--continued

<table>
<tr><th colspan="2">POURED GYPSUM DIAPHRAGMS</th></tr>
<tr><td>Inadequate in-plane shear capacity of the concrete diaphragm</td><td rowspan="3">1. Increasing the shear capacity by overlaying the existing concrete diaphragm with a new reinforced concrete topping slab.
2. Reducing the shear in the existing concrete diaphragm by providing supplemental vertical-resisting elements (i.e., shear walls or braced frames) as discussed in Sec. 3.4.
3. Increasing the flexural capacity by removing the edge of the diaphragm slab and casting a new chord member integral with the slab.
4. Adding a new chord member by providing a new reinforced concrete or steel member above or below the slab and connecting the new member to the existing slab with drilled and grouted dowels or bolts as discussed in Sec. 3.5.4.3.
5. Reducing the existing flexural stresses by providing supplemental vertical-resisting elements (i.e., shear walls or braced frames) as discussed in Sec. 3.4.
6. Reducing the local stresses by distributing the forces along the diaphragm by means of structural steel or reinforced concrete elements cast beneath the slab and made integral through the use of drilled and grouted dowels.
7. Increasing the capacity of the concrete by providing a new concrete topping slab in the vicinity of the opening and reinforcing with trim bars.
8. Removing the stress concentration by filling in the diaphragm opening with reinforced concrete.
9. Reducing the shear stresses at the location of the openings by adding supplemental vertical-resisting elements (i.e., shear walls or braced frames) as discussed in Sec. 3.4.
10. Adding a new horizontal bracing system may be the most effective strengthening alternative.</td></tr>
<tr><td>Inadequate diaphragm chord capacity</td></tr>
<tr><td>Excessive shear stresses at the diaphragm openings or plan irregularities</td></tr>
<tr><th colspan="2">PRECAST CONCRETE DIAPHRAGMS
(precast or post-tensioned concrete planks, tees, or cored slabs)</th></tr>
<tr><td>Inadequate in-plane shear capacity of the connections between the adjacent units</td><td>1. Replacing and increasing the capacity of the existing connections by overlaying the existing diaphragm with a new reinforced concrete topping slab.
2. Reducing the shear forces on the diaphragm by providing supplemental vertical-resisting elements (i.e., shear walls or braced frames) as discussed in Sec. 3.4.</td></tr>
<tr><td>Inadequate diaphragm chord capacity</td><td>1. Providing a new continuous steel member above or below the steel slab and connecting the new member to the existing slab with bolts.
2. Removing the edge of the diaphragm and casting a new chord member integral with the slab.
3. Reducing the diaphragm chord forces by providing supplemental vertical-resisting elements (i.e., shear walls or braced frames) as discussed in Sec. 3.4.</td></tr>
</table>

TABLE B4--continued

PRECAST CONCRETE DIAPHRAGMS--continued	
Excessive in-plane shear stresses at diaphragm openings or plan irregularities	1. Reducing the local stresses by distributing the forces along the diaphragm by means of concrete drag struts cast beneath the slab and made integral with the existing slab with drilled and grouted dowels. 2. Increasing the capacity by overlaying the existing slab with a new reinforced concrete topping slab with reinforcing trim bars in the vicinity of the opening. 3. Removing the stress concentration by filling in the diaphragm opening with reinforced concrete. 4. Reducing the shear stresses at the location of the openings by providing supplemental vertical-resisting elements (i.e., shear walls or braced frames) as discussed in Sec. 3.4.
STEEL DECK DIAPHRAGMS (steel decking on steel framing)	
Inadequate in-plane shear capacity which may be governed by the capacity of the welding to the supports or the capacity of the seam welds between the deck units	1. Increasing the steel deck shear capacity by providing additional welding. 2. Increasing the deck shear capacity of unfilled steel decks by adding a reinforced concrete fill or overlaying with concrete filled steel decks a new topping slab. 3. Increasing the diaphragm shear capacity by providing a new horizontal steel bracing system under the existing diaphragm. 4. Reducing the diaphragm shear stresses by providing supplemental vertical-resisting elements to reduce the diaphragm span as discussed in Sec. 3.4.
Inadequate diaphragm chord capacity	1. Increasing the chord capacity by providing welded or bolted continuity splices in the perimeter chord steel framing members. 2. Increasing the chord capacity by providing a new continuous steel member on top or bottom of the diaphragm. 3. Reducing the diaphragm chord stresses by providing supplemental vertical-resisting elements (i.e., shear walls or braced frames) such that the diaphragm span is reduced as discussed in Sec. 3.4.
Excessive in-plane shear stresses at diaphragm openings or plan irregularities	1. Reducing the local stress concentrations by distributing the forces into the diaphragm by means of steel drag struts. 2. Increasing the capacity of the diaphragm by reinforcing the edge of the opening with a steel angle frame welded to the decking. 3. Reducing the diaphragm stresses by providing supplemental vertical-resisting elements (i.e., shear walls, braced frames or new moment frames) such that the diaphragm span is reduced as discussed in Sec. 3.4.

TABLE B4--continued

HORIZONTAL STEEL BRACING	
Inadequate force capacity of the members (i.e., bracing and floor or roof beams) and/or the connections	1. Increasing the capacity of the existing bracing members or removing and replacing them with new members and connections of greater capacity. 2. Increasing the capacity of the existing members by reducing unbraced lengths. 3. Increasing the capacity of the bracing system by adding new horizontal bracing members to previously unbraced panels (if feasible). 4. Increasing the capacity of the bracing system by adding a steel deck diaphragm to the floor system above the steel bracing. 5. Reducing the stresses in the horizontal bracing system by providing supplemental vertical-resisting elements (i.e., shear walls or braced frames) as discussed in Sec. 3.4.

TABLE B5
FOUNDATIONS

CONTINUOUS OR STRIP WALL FOOTINGS	
Deficiency	**Strengthening Techniques**
Excessive soil bearing pressure due to overturning forces	1. Increasing the bearing capacity of the footing by underpinning the footing ends and providing additional footing area. 2. Increasing the vertical capacity of the footing by adding new drilled piers adjacent and connected to the existing footing. 3. Increasing the soil bearing capacity by modifying the existing soil properties. 4. Reducing the overturning forces by providing supplemental vertical-resisting elements (i.e., shear walls or braced frames) as discussed in Sec. 3.4.
Excessive uplift conditions due to overturning forces	1. Increasing the uplift capacity of the existing footing by adding drilled piers or soil anchors. 2. Increasing the size of the existing footing by underpinning to mobilize additional foundation and reduce soil pressures. 3. Reducing the uplift forces by providing supplemental vertical-resisting elements (i.e., shear walls or braced frames) as discussed in Sec. 3.4.
INDIVIDUAL PIER OR COLUMN FOOTINGS	
Excessive soil bearing pressure due to overturning forces	1. Increasing the bearing capacity of the footing by underpinning the footing ends and providing additional footing area. 2. Increasing the vertical capacity of the footing by adding new drilled piers adjacent and connected to the existing footing. 3. Reducing the bearing pressure on the existing footings by connecting adjacent footings with deep reinforced concrete tie beams. 4. Increasing the soil bearing capacity by modifying the existing soil properties. 5. Reducing the overturning forces by providing supplemental vertical-resisting elements (i.e., shear walls or braced frames).
Excessive uplift conditions due to overturning forces	1. Increasing the uplift capacity of the existing footing by adding drilled piers or soil anchors. 2. Increasing the size of the existing footing by underpinning to mobilize additional foundation and soil weight. 3. Increasing the uplift capacity by providing a new deep reinforced concrete beam to mobilize the dead load on an adjacent footing. 4. Reducing the uplift forces by providing supplemental vertical-resisting elements (i.e., shear walls or braced frames).

TABLE B5--continued

INDIVIDUAL PIER OR COLUMN FOOTINGS--continued	
Inadequate passive soil pressure to resist lateral loads	1. Providing an increase in bearing area by underpinning and enlarging the footing. 2. Providing an increase in bearing area by adding new tie beams between existing footings. 3. Improving the existing soil conditions adjacent to the footing to increase the allowable passive pressure. 4. Reducing the bearing pressure at overstressed locations by providing supplemental vertical-resisting elements such as shear walls or braced frames as discussed in Sec. 3.4.
PILES OR DRILLED PIERS	
Excessive tensile or compressive loads on the piles or piers due to the seismic forces combined with the gravity loads	1. Increasing the capacity of the foundation by removing the existing pile cap, driving additional piles and providing new pile caps of larger size. 2. Reducing the loads on overstressed pile caps by adding tie beams to adjacent pile caps and distributing the loads.
Inadequate lateral force capacity to transfer the seismic shears from the pile caps and the piles to the soil	1. Reducing the loads on overstressed pile caps by adding tie beams to adjacent pile caps and distributing the loads. 2. Increasing the allowable passive pressure of the soil by improving the soil adjacent to the pile cap. 3. Increasing the capacity of the foundation by removing the existing pile cap, driving additional piles, and providing new pile caps of larger size. 4. Reducing loads on the piles or piers by providing supplemental vertical-resisting elements (i.e., braced frames or shear walls) and transferring forces to other foundation members with reserve capacity as discussed in Sec. 3.4.
MAT	
Inadequate moment capacity to resist combined gravity plus seismic overturning forces	1. Increasing the mat capacity locally by providing additional reinforced concrete (i.e., an inverted column capital) doweled and bonded to the existing mat to act as a monolithic section. 2. Providing new shear walls above the mat to distribute the overturning loads and also to locally increase the section modulus of the mat.
Inadequate passive soil pressure to resist sliding	1. Constructing properly spaced shear keys at the mat perimeter.

TABLE B6
DIAPHRAGM TO VERTICAL ELEMENT CONNECTIONS

CONNECTIONS OF TIMBER DIAPHRAGMS	
Deficiency	**Strengthening Techniques**
Inadequate capacity to transfer in-plane shear at the connection of the diaphragm to interior shear walls or vertical bracing	1. Increasing the shear transfer capacity of the diaphragm local to the connection by providing additional nailing to existing or new blocking. 2. Reducing the local shear transfer stresses by distributing the forces from the diaphragm by providing a collector member to transfer the diaphragm forces to the shear wall. 3. Reducing the shear transfer stress in the existing connection by providing supplemental vertical-resisting elements as discussed in Sec. 3.4.
Inadequate capacity to transfer in-plane shear at the connection of the diaphragm to exterior shear walls or vertical bracing	1. Increasing the capacity of existing connections by providing additional nailing and/or bolting. 2. Reducing the local shear transfer stresses by distributing the forces from the diaphragm by providing chords or collector members to collect and distribute shear from the diaphragm to the shear wall or bracing. 3. Reducing the shear stress in the existing connection by providing supplemental vertical-resisting elements as discussed in Sec. 3.4.
Inadequate out-of-plane anchorage at the connection of the diaphragm to exterior concrete or masonry walls	1. Increasing the capacity of the connection by providing steel straps connected to the wall (using drilled and grouted bolts or through bolts for masonry walls) and bolted or lagged to the diaphragm or roof or floor joists. 2. Increasing the capacity of the connections by providing a steel anchor to connect the roof or floor joists to the walls. 3. Increasing the redundancy of the connection by providing continuity ties into the diaphragm.
Inadequate tensile capacity between floors due to overturning moments	1. Increasing the tensile capacity of the connections at the edge of the shear walls by providing metal connectors. 2. Reducing the overturning moments by providing supplemental vertical-resisting elements as discussed in Sec. 3.4.

TABLE B6--continued

CONNECTIONS OF CONCRETE DIAPHRAGMS	
Inadequate in-plane shear transfer capacity	1. Reducing the local stresses at the diaphragm-to-wall interface by providing collector members or drag struts under the diaphragm and connecting them to the diaphragm and the wall. 2. Increasing the capacity of the existing diaphragm-to-wall connection by providing additional dowels grouted into drilled holes. 3. Reducing the shear stresses in the existing connection by providing supplemental vertical-resisting elements as discussed in Sec. 3.4.
Inadequate anchorage capacity for out-of-plane forces in the connecting walls	1. Increasing the capacity of the connection by providing additional dowels grouted into drilled holes. 2. Increasing the capacity of the connection by providing a new member above or below the slab connected to the slab with drilled and grouted bolts similar to that for providing a new diaphragm chord.
CONNECTIONS OF POURED GYPSUM DIAPHRAGMS	
Inadequate in-plane shear transfer Inadequate anchorage capacity for out-of-plane forces in the connecting walls	1. Providing new dowels from the diaphragm into the shear wall. 2. Removing the gypsum diaphragm and replacing it with steel decking. 3. Adding a new horizontal bracing system designed to resist all of the seismic forces.
CONNECTIONS OF PRECAST CONCRETE DIAPHRAGMS	
Inadequate in-plane shear transfer capacity Inadequate anchorage capacity at the exterior walls for out-of-plane forces	1. Increasing the capacity of the connection by providing additional welded inserts or dowels placed in drilled or grouted holes. 2. Increasing the capacity of the connection by providing a reinforced concrete overlay that is bonded to the precast units and anchored to the wall with additional dowels placed in drilled and grouted holes. 3. Reducing the forces at the connection by providing supplemental vertical-resisting elements as discussed in Sec. 3.4.

TABLE B6--continued

CONNECTIONS OF STEEL DECK DIAPHRAGMS WITHOUT CONCRETE FILL	
Inadequate in-plane shear capacity or anchorage capacity for out-of-plane forces in walls	1. Increasing the capacity of the connection by providing additional welding at the vertical element. 2. Increasing the capacity of the connection by providing additional anchor bolts. 3. Increasing the capacity of the connection by providing concrete fill over the deck with dowels grouted into holes drilled into the wall. 4. Increasing the capacity of the connection by providing new steel members to effect a direct transfer of diaphragm shears to a shear wall. 5. Reducing the local stresses by providing additional vertical-resisting elements such as shear walls, braced frames, or moment frames as discussed in Sec. 3.4.
CONNECTIONS OF STEEL DECK DIAPHRAGMS WITH CONCRETE FILL	
Inadequate in-plane shear capacity or anchorage capacity for out-of-plane forces in walls	1. Increasing the shear capacity by drilling holes through the concrete fill, and providing additional shear studs welded to the vertical elements through the decking. 2. Increasing the capacity of the connection by providing additional anchor bolts (drilled and grouted) connecting the steel support to the wall. 3. Increasing the capacity of the connection by placing dowels between the existing wall and diaphragm slab. 4. Reducing the local stresses by providing additional vertical-resisting elements such as shear walls, braced frames, or moment frames as discussed in Sec. 3.4.
CONNECTIONS OF HORIZONTAL STEEL BRACING	
Inadequate in-plane shear transfer capacity	1. Increasing the capacity by providing larger or more bolts or by welding. 2. Reducing the stresses by providing supplemental vertical-resisting elements such as shear walls or braced frames as discussed in Sec. 3.4.
Inadequate anchorage capacity when supporting concrete or masonry walls for out-of-plane forces	1. Increasing the capacity of the connection by providing additional anchor bolts grouted in drilled holes and by providing more bolts or welding to the bracing members.

TABLE B7
VERTICAL ELEMENT TO FOUNDATION CONNECTIONS

CONNECTIONS OF WOOD STUD SHEAR WALLS	
Deficiency	**Strengthening Techniques**
Inadequate shear capacity of the anchorage	1. Increasing the shear capacity by providing new or additional anchor bolts between the sill plate and the foundation. 2. Increasing the shear capacity by providing steel angles or plates with anchor bolts connecting them to the foundation and bolts or lag screws connecting them to the sill plate or wall.
Inadequate shear capacity of cripple stud walls	1. Adding plywood sheathing over the cripple studs (usually on the inside) by nailing into the floor framing and the sill plate. Anchorage of the sill plate to the foundation also must be provided.
Inadequate uplift capacity	1. Increasing the capacity by providing steel hold-downs bolted to the wall and anchored to the concrete. 2. Reducing the uplift requirement by providing supplemental shear walls as discussed in Sec. 3.4.
CONNECTIONS OF METAL STUD SHEAR WALLS	
Inadequate shear capacity of the anchorage	1. Provide anchor bolts, grouted in drilled holes, through sill plate of wall. 2. Provide steel angles with anchor bolts to concrete and bolts or screws to wall.
Inadequate shear capacity of cripple stud walls	1. Provide plywood sheathing, nailing into cripple studs, sill plate, and first floor framing; anchor sill plate to foundation.
Inadequate uplift capacity	1. Provide steel hold-down with bolts or screws to wall and anchor bolts to concrete at ends of shear wall. 2. Provide additional shear walls or vertical bracing.
CONNECTIONS OF PRECAST CONCRETE SHEAR WALLS	
Inadequate capacity to resist in-plane or out-of-plane shear forces	1. Increasing the capacity of the connection by providing a new steel member connecting the wall to the foundation or the ground floor slab. 2. Increasing the capacity of the connection by adding a new thickness of concrete (either cast-in-place or shotcrete) placed against the precast wall doweling into the existing foundation or ground floor slab.

TABLE B7--continued

CONNECTIONS OF PRECAST CONCRETE SHEAR WALLS--continued	
Inadequate hold-down capacity to resist seismic overturning forces	1. Increase the hold-down capacity by removing concrete at the edge of the precast unit to expose the reinforcement provide, new drilled and grouted dowels into the foundation, and pour a new concrete pilaster. 2. Reduce the uplift forces by providing supplemental vertical-resisting elements such as shear walls or braced frames as discussed in Sec. 3.4.
CONNECTIONS OF BRACED FRAMES	
Inadequate shear capacity	1. Increasing the capacity by providing new steel members welded to the braced frame base plates and anchored to the slab or foundation with drilled and grouted anchor bolts. 2. Reducing the shear loads by providing supplemental steel braced frames as discussed in Sec. 3.4.
Inadequate uplift resistance	1. Increasing the capacity by providing new steel members welded to the base plate and anchored to the existing foundation. 2. Reducing the uplift loads by providing supplemental steel braced frames as discussed in Sec. 3.4.
CONNECTIONS OF STEEL MOMENT FRAMES	
Inadequate shear capacity Inadequate flexural capacity Inadequate uplift capacity	1. Increasing the shear capacity by providing steel shear lugs welded to the base plate and embedded in the foundation. 2. Increasing the shear and tensile capacity by installing additional anchor bolts into the foundation. 3. Increasing the shear capacity by embedding the column in a reinforced concrete pedestal that is bonded or embedded into the existing slab or foundation.

APPENDIX C

REHABILITATION EXAMPLES*

Two examples are included in this appendix to demonstrate the process of selecting appropriate seismic rehabilitation techniques: a two-story steel frame building and a two story unreinforced masonry building. Both buildings were evaluated to determine their seismic deficiencies in accordance with the *NEHRP Handbook for the Seismic Evaluation of Existing Buildings* (which includes the evaluations as Examples D1 and D6 in Appendix D).

C1 TWO-STORY STEEL FRAME BUILDING EXAMPLE

C1.1 DESCRIPTION OF BUILDING

The building is 200 ft by 340 ft in plan with 20 ft by 20 ft bays. The girders in the transverse direction are connected to the column flanges with top and bottom clip angles. The beams in the longitudinal direction are connected to the column webs with beam web connections. The floor and roof diaphragms consists of steel decking with concrete fill.

C1.2 DEFICIENCIES

Inadequate moment capacity in both directions.

C1.3 STRENGTHENING ALTERNATIVES

This building could be strengthened by providing adequate moment capacity to the existing frames, by providing new diagonal bracing, and/or by providing new shear walls

C1.3.1 Providing Adequate Moment Capacity

Assuming that the first story shear of 2,970 kips can be equally distributed to all columns, it is calculated that there is excess capacity for the columns in the transverse direction (i.e., the strong axis of the columns) but grossly inadequate capacity for the columns in the longitudinal direction (i.e., the weak axis of the columns). This indicates that it is not feasible to develop adequate frame action to resist the seismic forces in the longitudinal direction, but it is feasible in the transverse direction. The structural modifications (Figure C1.3.1) required to develop moment frame action will involve:

1. Removal of the concrete fill and steel decking over the ends of the transverse girders at the columns. (It is assumed that the steel decking is supported on secondary floor beams that frame into the transverse frame girders so that there are no adverse effects associated with removal of the decking over top flanges of these girders adjacent to the columns.)

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*The American Iron and Steel Institute has written a minority opinion concerning this appendix; see page 193.

2. Addition of new vertical shear connections between the girder webs and the column flanges.

3. Removal of existing clip angles at the top and bottom flanges of the girders.

4. Addition of new moment plates welded at the top and bottom flanges of the girders.

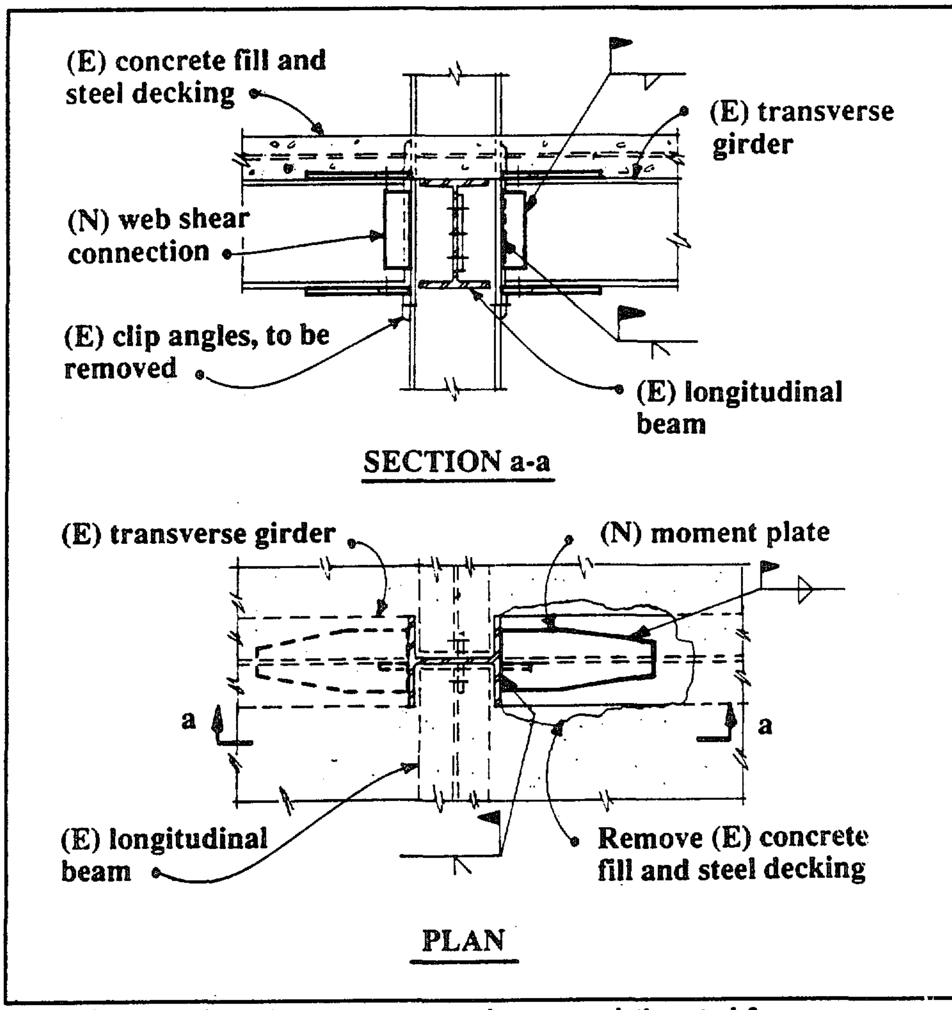

FIGURE C1.3.1 Providing moment capacity to an existing steel frame.

The design of these modifications should provide moment plates that are sized so as to yield prior to inducing yield stress in the columns. The new girder web shear connections should be sized for the gravity load shears (i.e., dead and live load) plus the shears associated with the formation of yield hinges in the moment plates. The column section of the new frame joint must be checked to determine the possible need for horizontal stiffeners opposite the girder flanges. The column web also should be checked to determine the need for doubler plates. Stiffeners probably can be fitted above or below the existing longitudinal beams at the column, but if doubler plates are required, this alternative may not be feasible because of interference with the existing longitudinal beam connection.

C1.3.2 Providing New Diagonal Bracing

Assume that diagonal bracing is to be considered for the longitudinal direction of the building. If the existing diaphragms have adequate capacity, the new bracing can be located in the exterior walls to avoid possible interference with the internal circulation within the building. If the diaphragm has inadequate capacity to transfer the seismic shears to the exterior longitudinal walls, it probably would be more cost-effective to brace one or more of the interior longitudinal frames rather than to strengthen the diaphragm.

In the design of the vertical bracing, X-bracing will be more effective than diagonal or chevron bracing for most braced bays because the tension diagonal will provide lateral support for the compression diagonal. Many designers assume that the effective length of the compression diagonal for X-bracing may be taken as one-half of the diagonal length for the in-plane direction and two-thirds of the diagonal length for the out-of-plane direction. Since the greater L/r will govern the capacity of the brace, this leads to the use of brace members with different radii of gyration, r, about each axis.

The number of braced bays must be adequate to resist the story shears; however, in this building the story shears are not severe and can easily be resisted with only a fraction of the number of bays available in the exterior longitudinal frames. Next, the existing columns and foundations must be investigated for the overturning loads in the bracing. If it is assumed that all braces are equally loaded, it should be noted that with multiple contiguous bays of X-bracing there are no additional vertical forces in the columns and foundations except at the extreme ends of the braced bays. Therefore, if the existing columns or foundations do not have adequate capacity for the calculated overturning loads in the bracing, the engineer may be able to reduce these loads to acceptable limits by using smaller brace members and increasing the number of braced bays. The required structural modifications (Figure C1.3.2) involve:

1. Removal of the existing concrete fill and steel decking at second floor and roof levels to permit welding of gusset plate to beam flange. Since the gusset is to be welded along the center of the beam flange, only a narrow section of decking needs to be removed. Care must be taken that adequate bearing remains for the decking.
2. Welding of gusset plates to the beam/column joints and to the column/base plate joints.
3. Welding of new diagonal braces to the gusset plates.

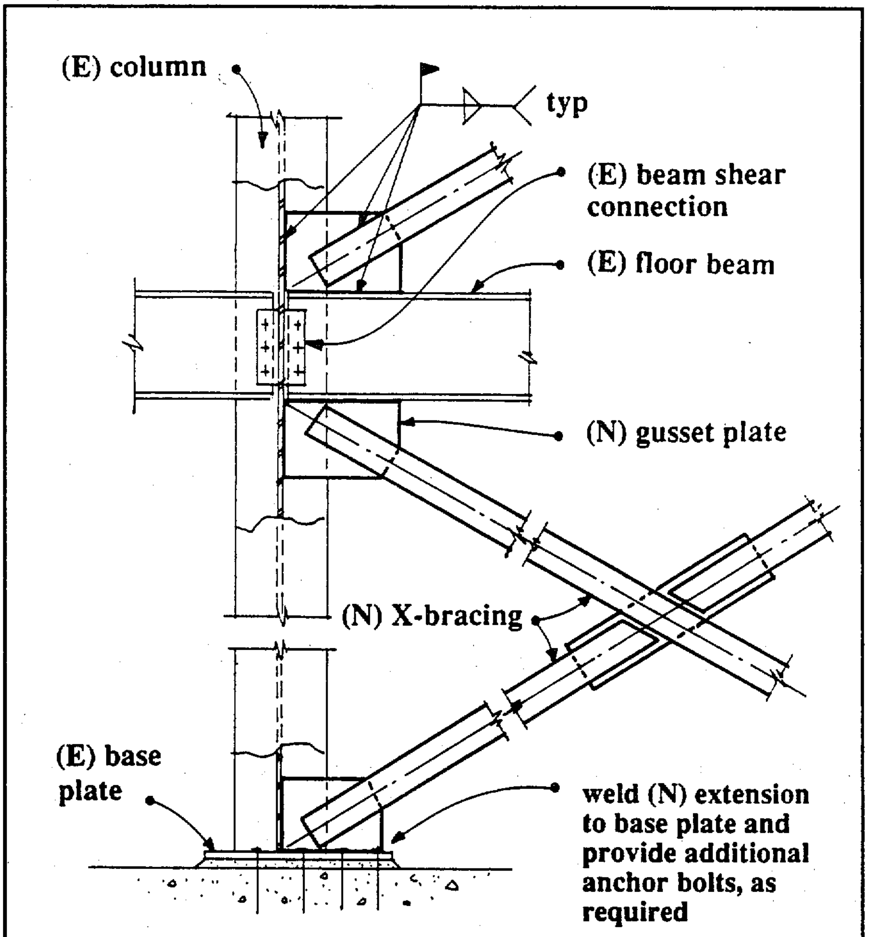

FIGURE C1.3.2 Providing new diagonal bracing to an existing steel frame.

The design of the new bracing system must include a structural investigation of the capacity of the existing columns, beams, and foundations to resist the additional forces associated with the new bracing. It should be noted that the floor beams in the braced frames are required to function as collector members to "collect" the diaphragm shears and distribute them to the braced bays. The beam-to-column connection must therefore be capable of transferring tensile or compressive forces as well as resisting the vertical reaction of the floor beams.

C1.3.3 Providing New Shear Walls

New shear walls of reinforced concrete or reinforced masonry may be provided in lieu of bracing or frame action in either direction of the building. If shear walls are provided, they should be infilled bays on a column line and preferably in a location where window or door openings are not required. With infill walls, the columns can function as boundary members for overturning loads and the beams or girders as collector members for the shear walls. The shear walls probably will require new foundations and also will add significantly to the building mass, which will increase the seismic story shears.

C1.4 RELATIVE MERITS OF THE ALTERNATIVE STRENGTHENING TECHNIQUES

As indicated above, the frame columns have inadequate capacity to resist the seismic story shears in the longitudinal direction; therefore, new vertical bracing or shear walls are the available options. It appears that the bracing could be installed in the exterior longitudinal frames without strengthening the columns or the foundations whereas the shear walls probably would need new foundations and be more disruptive as well as requiring more time for construction.

In the transverse direction, providing moment capacity to the existing frames (Figure C1.3.1) appears to be feasible. It appears that this would be required for about two-thirds of the frames in the transverse direction at the second floor level and only about one-half of the frames at the roof level.

Preliminary design of the structural strengthening concepts should be performed to define the location and extent of the modifications and to size the new structural members. Relative costs for the various alternatives also should be developed and attention should be given to the other considerations described at the beginning of Chapter 3. With this information, the most appropriate seismic strengthening technique for the building can be selected.

C2 UNREINFORCED MASONRY BUILDING EXAMPLE

C2.1 DESCRIPTION OF BUILDING

This building is a two-story structure, 30 ft by 100 ft in plan. The first level has an open front at the east end and a longitudinal bearing wall on the centerline of the building. There are no crosswalls in the first level, but the second level contains apartments with many crosswalls. The roof diaphragm is constructed of diagonal timber sheathing. The floor contains finished wood flooring over timber diagonal sheathing. The existing conditions are shown in Figure C2.1.

C2.2 DEFICIENCIES

The building's deficiencies involve:

1. Torsion--The east end of the building has negligible resistance to lateral loads at the first level and constitutes a severe seismic hazard.

2. Adjacent Building--The adjacent building on the south side is not separated from the south wall and would act as a buttress for the diaphragms of the subject building. This could result in damage to both buildings.

3. Wall Stability--The gabled east and west walls at the second level are too slender (i.e., 9 in.) for the calculated out-of-plane seismic response imparted by the roof diaphragm.

4. Wall Anchorage--There is a serious inadequacy in the anchorage of all walls to the floor and roof diaphragms.

5. **In-Plane Shear Strength of Walls--In addition to the obvious deficiency in the open east wall at the first level, there also are potential deficiencies in the remaining east and west walls at both levels.**

6. **Parapet--The 9-in. unreinforced masonry walls in the second level terminate in an unsupported 18-in. high parapet above the roof level that may be a hazard to life safety in a severe earthquake.**

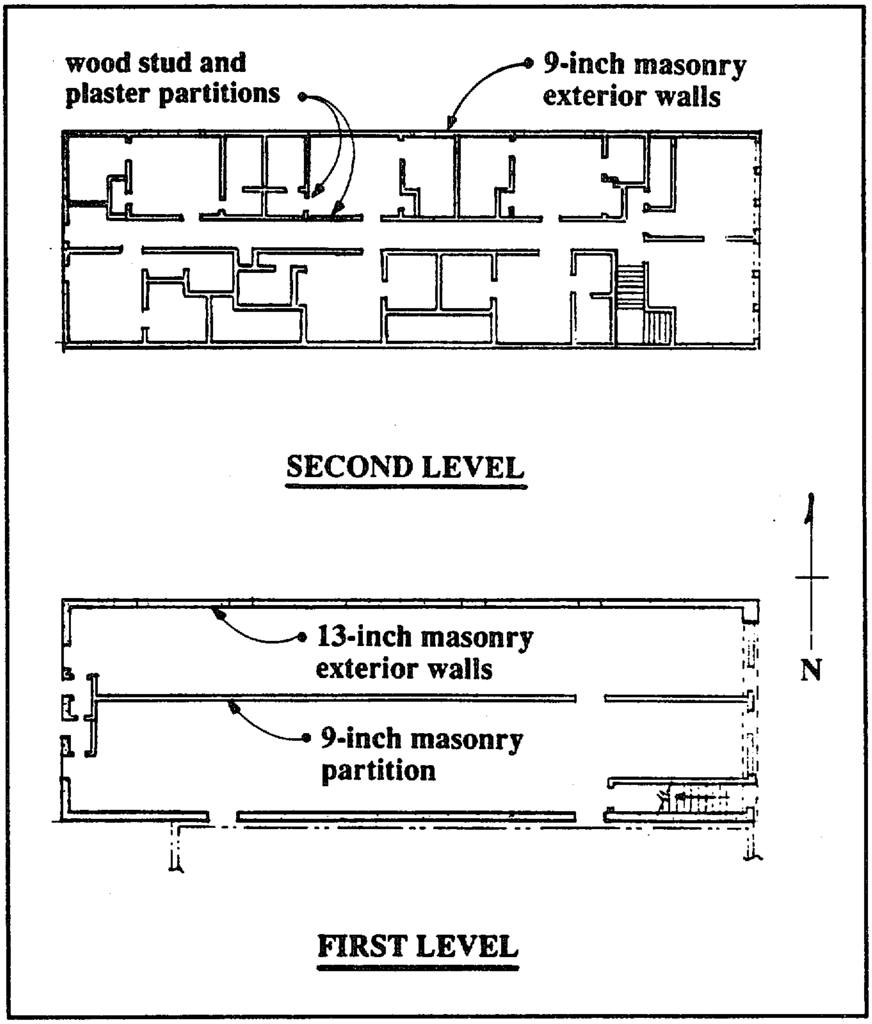

FIGURE C2.1 Existing two-story unreinforced masonry building.

C2.3 STRENGTHENING TECHNIQUES

The structural evaluation of this building was conducted using the ABK Methodology for unreinforced masonry bracing wall buildings with wood diaphragms. The recommended strengthening techniques (Figure C2.3) also follow that methodology.

C2.3.1 Torsion

The east wall of the building is deficient in both strength and stiffness. In addition, extensive wall anchors are required at both the first and second levels. Although the open front condition at the first level could be improved with either a concrete or steel moment frame, the extensive additional work required for this wall and its foundation combine to make replacement an attractive alternative.

Replacement of the existing east wall with a two-story reinforced concrete frame is the recommended strengthening alternative. Since the roof and second floor joists are supported on the longitudinal walls, shoring will not be required as the east wall is removed. Temporary lateral bracing in the north-south direction should be utilized during the replacement of the east wall. The new second level wall would be a metal stud wall with window openings similar to the existing ones and with brick veneer to match the other brick walls, if desired.

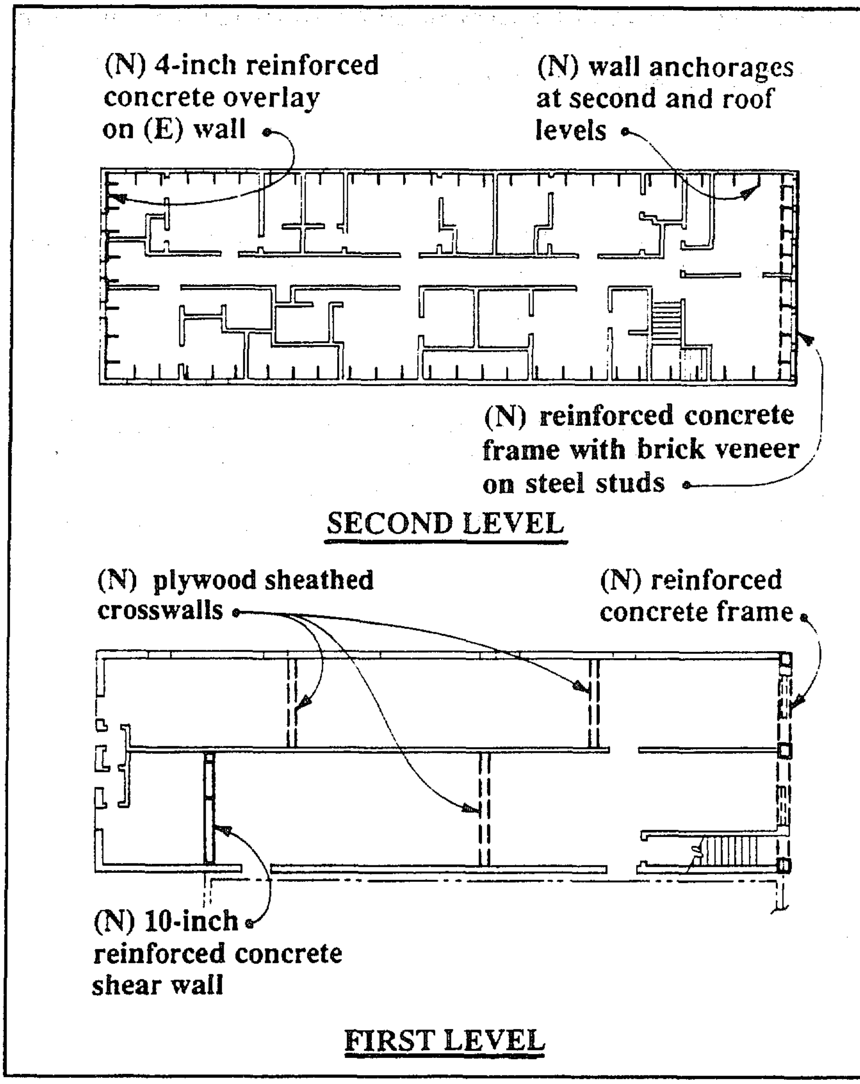

FIGURE C2.3 Proposed structural modifications.

C2.3.2 Adjacent Building

The proposed solution to the problem with the adjacent building is to provide a new reinforced concrete shear wall in the first level of the subject building. The wall would be in line with the west wall of the adjacent building. In addition to the new shear wall, three new timber cross walls will be provided in the first level (Figure C2.3) to reduce the diaphragm deflection. The shear wall, the cross walls, and their connections to the floor diaphragm will be designed in accordance with the ABK Methodology. This strengthening may not completely solve the adjacent building problem, but the new shear wall and the cross walls will significantly reduce the inertia forces transmitted to the adjacent building.

C2.3.3 Wall Stability

The height to thickness ratio, h/t, of an unreinforced masonry wall is used as an index of the stability of the wall for the out-of-plane seismic response induced by the diaphragm. The east wall is to be replaced with a reinforced concrete wall so that the west wall in the second level is the only remaining wall with an excessive h/t ratio. The deficiency can be corrected by providing anchors at the ceiling level and bracing this anchorage up to the wood diaphragm or by designing vertical wall braces that span from the floor to the roof anchorage level.

C2.3.4 Wall Anchorage

All anchorages of masonry walls to diaphragms were found to be inadequate at both levels of the building. Supplementary anchors must be provided for the calculated anchorage. The anchors should be similar to those indicated in Figure 3.7.1.4a or b. Significantly greater allowable loads are permitted for anchors that extend through the masonry wall with a large metal washer on the outside of the wall. This type of anchor should be used in all locations where access is available to the outside face of the wall.

C2.3.5 In-Plane Shear Stress

The new reinforced concrete frame at the east wall, the new shear wall, and the new concrete overlay for the west wall at second level have eliminated the calculated in-plane overstress in the east and west walls.

C2.3.6 Parapet

The unreinforced and unbraced parapet is a life safety hazard because of its *h/t* ratio. It is recommended that the parapet be reduced in height by the removal of several courses of brick (i.e., 8 to 10 in.). This should be preceded by a horizontal saw cut at a mortar joint on both sides of the wall to avoid damage to the remaining brickwork. The top of the reduced parapet then should be sealed with a mortar cap to prevent intrusions of moisture into the wall.